Trends in Biotechnology

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Opinion

Towards Food Security: Current State and Future Prospects of Agrobiotechnology☆

Agata Tyczewska,[1] Ewa Woźniak,[1] Joanna Gracz,[1] Jakub Kuczyński,[1] and Tomasz Twardowski[1,*]

The consistent increase in the global population, estimated to reach 9 billion people by 2050, poses a serious challenge for the achievement of global food security. Therefore, the need to feed an increasing world population and to respond adequately to the effects of climate change must be urgently considered. Progress may be achieved by applying knowledge of molecular and genetic mechanisms to create and/or improve agricultural and industrial processes. We highlight the importance of crops (wheat, maize, rice, rapeseed, and soybean) to the development of sustainable agriculture and agrobiotechnology in the EU and discuss possible solutions for ensuring food security, while also considering their social acceptance.

Highlights

Fast human population growth and less-than-required increases in crop production in recent years obligate coordinated efforts from scientists, farmers, producers and consumers to ensure food security.

Recent progress in molecular biology and biotechnology creates hope for the future. With the help of genetic engineering techniques, scientists continue to improve crops in an effort to diminish losses caused by biotic and abiotic stresses and increase yield.

Crosstalk between scientists and society based on reliable scientific knowledge is urgently needed, as is appropriate legislation.

Challenges in Ensuring Global Food Security

One of the societal, economic, and scientific challenges of the modern world is the constantly growing human population. It has been estimated that by 2050 the global population will exceed 9 billion people [1]. Unfortunately, current food production levels are not sufficient to meet the demand of such a large population. Achieving global **food security** (see Glossary) by 2050 will be challenging and unless we take vital action to prevent devastating ripple effects, the agriculture sector will be affected by changes in climate and soil deterioration that will further challenge the productivity of the world's agricultural resources.

The easiest way to overcome the 'not enough food' problem would be to increase the acreage of farmable land. Unfortunately, the vast majority of arable agricultural land is unavailable, as it is already being used for various types of agriculture. According to World Bank data, 37.3% of the world's total land area in 2015 was considered agricultural, while approximately 11% (1.5 billion hectares) was considered arable[i,ii]. According to the UN Food and Agriculture Organization (FAO), an increase in crop production potential is still possible, as approximately 2.7 billion ha remains available for further expansion of agricultural land[iii]. However, most of this land is concentrated in Africa and Central and South America, areas with harsh geoclimatic conditions; it may be prohibitively difficult to use these areas for farming.

Over the past 40 years, one-third of the world's **arable land** has been lost to erosion or pollution [2]. The rate of erosion occurring in **agricultural areas** is, in most cases, higher than the rate of soil formation and leads to the removal of organic matter and nutrients, the loss of soil structure, and a decrease in water-holding abilities [2]. To obtain the highest possible yields, farmers must reintroduce nutrients into the soil via heavy fertilization. Disease control is also maintained by chemical supplementation – the use of pesticides and insecticides that further destroy farmlands[iv,v] [3]. Currently, such heavy use of chemicals is being justified by losses caused by biotic and abiotic **stresses**, as direct yield losses caused by pathogens, animals, and weeds are reaching between 20% and 40% of global agricultural productivity [4–7].

[1]Institute of Bioorganic Chemistry Polish Academy of Sciences, Poznań, Poland

☆Website of the Protein Biosynthesis Group at the Institute of Bioorganic Chemistry PAS in Poznań: https://www.ibch.poznan.pl/structure/department-of-protein-biosynthesis/.

*Correspondence:
twardows@ibch.poznan.pl
(T. Twardowski).

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Climate change is among the principal limiting factors causing a decline in agricultural productivity. Drought, extreme temperatures, flooding, salinity, acidic conditions, and nutrient starvation are the world's most dominant abiotic stresses [8–13]. Extreme temperatures and precipitation prevent crops from growing; increased CO_2 levels affect crop yields and reduce the nutritional value of food crops, while providing ideal conditions for the growth of many weeds, pests, and fungi. Cheerlessly, as stated by the FAO in 2007, only 3.5% of global agricultural areas were not affected by any of these environmental stresses [14].

The matter of food production in a perspective of fast population growth becomes urgent now, especially in the face of climate change. It is important not only to face the challenges associated with providing sufficient amounts of food but also to learn to manage resources in a sustainable manner, while diminishing negative impacts exerted on the environment. Therefore, we describe possible solutions to these problems, mainly focused on the use of new engineering techniques in developing improved plant varieties and benefits resulting from the use of **genetically modified (GM) organisms (GMOs)**. We also pinpoint the challenges associated with the public perception and legislation of GM varieties.

Crops for World Food Security

As a result of thousands of years of agriculture, domestication, and the gradual, long-term introduction of changes by natural and human-directed selection, many crop varieties have become the basis of the human daily diet and animal feed. Among 400 000 plant species, fewer than 200 have been domesticated and used as sources of food and feed and 12 provide up to 75% of the food consumed around the world [15]. It has been estimated that to meet the needs of the growing human population, global food production must be doubled (2.4% increase per year over the next 30 years) [16], a rate difficult to obtain because the actual increments in the yields of four key global crops (maize, rice, wheat, and soybean) have been estimated to be 1.6%, 1.0%, 0.9%, and 1.3% per year [16]. Figure 1 shows the global increases in maize, wheat, rice, and soybean production since the 1960s against population growth and predictions until 2050. The increase in the production rate between the year 1961 and 2016 for the most important crops is given in Table 1. The highest production growth over this period occurred for rapeseed and soybean. Compared with 1961, rapeseed production increased more than 18 times, achieving a production of nearly 69 million tons in 2016. Despite these two crops having the highest production growth, they had the least production compared with the other crops presented.

Cereals occupy the main position in the composition of the human diet, with rice, wheat, and maize being the major staple cereals, possessing a share in excess of 70% among all food grains [17]. The uses of the main crops in various industries in EU countries and in the world in 2017 are given in Table 2. A greater utilization of cereals, particularly wheat and rice, for food in the near future was highlighted in the FAO's latest forecast[vi]. The use of coarse grains for animal feed is also predicted to reach an all-time high[vii]. The OECD-FAO Agricultural Outlook 2017-2026[vi] estimates that future growth in crop production will be attained mostly by increasing yields (e.g., global wheat production in 2026 is estimated to increase to 820 million tons, 61 million tons more than in 2017). Nevertheless, according to some forecasts, crop production levels will increase to the required levels [16]. Therefore, the most pressing question is how to ensure food security, if not via an increase in global crop area?

The Importance of GM Plants in Agricultural Production

Over the past few decades, tremendous progress has been made in revealing the genetic basis of various plants' traits (Box 1). One of the most distinct achievements of this era was the

Glossary

Agricultural area: according to the FAO, the sum of areas considered 'arable land', 'permanent crops' (cultivated with long-term crops that do not have to be replanted for several years; land under trees and shrubs producing flowers, and nurseries, except those for forest trees), and 'permanent pastures' (used permanently – for 5 years or more – to grow herbaceous forage crops, either cultivated or growing wild, including wild prairie and grazing land).
Agrobiotechnology: also called green biotechnology or agricultural biotechnology, the use of technology based on molecular biology in the agriculture, forestry and food industries. The most common and controversial form of biotechnology in agriculture is the cultivation of new varieties of plants, called GM plants.
Arable land: according to the FAO, land under temporary agricultural crops, in temporary meadows for mowing or pasture, under market or kitchen gardens, or temporarily fallow (for less than 5 years). The abandoned land resulting from shifting cultivation is not included in this category. Data for 'arable land' are not meant to indicate the amount of land that is potentially cultivable.
Bioeconomy: all industries and economic sectors that produce or exploit biological resources and related services. The bioeconomy is commonly understood to be a complex of issues related to the safety and security of food and energy, climate change, and environmental protection as well as many social (employment, rural development, and inclusiveness) and cultural changes. The bioeconomy also includes the traditional sectors of the economy (e.g., agriculture, food industry, energy industry, wood and cellulose industry) that produce bioproducts and services using biotechnologies. The most recent direction is towards a circular bioeconomy.
Food security: determines foods that are sufficient, safe, and nutritious to meet dietary needs and food preferences for an active and healthy life in all people at all times (World Food Summit, 1996). There are three dimensions to this concept:

creation of GM plants. Some observers initially perceived GM crops as practically a miracle solution to all of the world's food security problems, as this technology undoubtedly has a great impact in overcoming limitations of classic breeding approaches. However, many concerns related to transgenic technology (economic as well as societal, environmental, and human health related) were subsequently raised. Nevertheless, the number of GM crops and their cultivated area are constantly increasing, and after 20 years of GM crops first being available, the acreage planted to GM crops increased nearly 100-fold to 189.8 million ha in 2017, compared with 1.7 million ha in 1996, when the first transgenic crops received approval for large-scale production[viii].

Soybean and maize crops possessing herbicide tolerance (HT) and insecticide tolerance (IT) traits are the most popular GM crops cultivated on a global scale[viii]. Those GM plants belong to the so-called first-generation GMOs, which are mostly utilized for pest control, either through resistance to arthropods or fungi or tolerance to herbicides. Such modifications are a great example of alterations in plant genetic material that help plants cope with biotic stresses. According to Ercoli and colleagues [18], plants with HT, IT, or both (soybean, maize, canola, and cotton) were planted on 179.6 million ha of the 185.1 million ha of total acreage of GM crops in 2016.

To date, 40 genetic modifications have been registered in soybeans, of which 18 are commercially available[ix] (a full list of GM events can be found on the ISAAA website). Besides the creation of HT and IT soybeans, a variety with an improved fatty acid profile was generated in 2009 [19]. It belongs to a second generation of GMOs, which contain traits improving crop properties like shelf life or enhanced nutritional value (referred to as biofortification) [20]. Soybean oil is characterized by low oxidative stability, which limits its uses in food products and industrial applications; therefore, to increase the stability, a variety with an oleic fatty acid content (instead of linoleic acid) greater than 80% has been introduced [19]. Another interesting example of second-generation modifications in soybean are plants with a silenced gene encoding the major immunodominant soybean allergen protein Gly m Bd 30K [21]. This GM variety helps to address food allergies, which are consistently rising in the industrialized world [22].

GM maize, despite its second position in GM crop cultivation acreage, has as many as 231 modifications registered[ix]. Most of them are, as in the case of soybean, related to HT and IT traits, but there are also examples of plants with increased drought tolerance [23], methionine content [24], or iron bioavailability [25,26]. In rapeseed, 45 GM events have been registered for two plant species commonly referred to as canola: *Brassica napus* and *Brassica rapa*. They include modifications such as HT, increased triacylglyceride levels with esterified lauric acid, and the introduction of a gene encoding the 3-phytase enzyme from *Aspergillus niger*, which makes plant phosphorus available to monogastric animals[ix].

For the most important crops in the human diet, wheat and rice, the commercialization of GM varieties encountered some obstacles. Until now, only one wheat variety resistant to glyphosate (MON71800) has been registered[ix], but it is not being cultivated anywhere for economic reasons: farmers are afraid to lose a market share due to public reluctance towards GMO consumption [27]. Recently, CRISPR–Cas9 technology has been used to simultaneously modify 3 TaMLO (*Triticum aestivum* mildew-resistant locus) homologs in a single wheat plant [28]. This attempt has conferred heritable broad-spectrum resistance to powdery mildew. Wheat plants are also being fortified with nutrients: GM lines with modified gluten content [29], α-amylase levels [30], and iron bioavailability [31] have already been created.

availability, accessibility, and adequacy. Availability means having enough accessible food to keep the human population alive. Accessibility refers to the ability to regularly acquire adequate quantities of food for a nutritional diet. Adequacy means that consumed food must have a positive nutritional impact on people.

Genetically modified organism (GMO): any organism, with the exception of humans, whose genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination.

New breeding techniques (NBTs): methods for developing new varieties in a faster and more precise manner than conventional breeding techniques by modifying the DNA of seeds and cells, allowing a number of limitations of conventional breeding to be overcome. Some of these methods include the zinc-finger nucleases (ZFNs), TALENs, and the meganuclease and CRISPR systems.

Stress: any unfavorable condition or substance that affects or blocks the metabolism, growth, or development of an organism. Biotic stresses originate through interactions between organisms, while abiotic stresses are those that depend on the interaction between organisms and the physical environment.

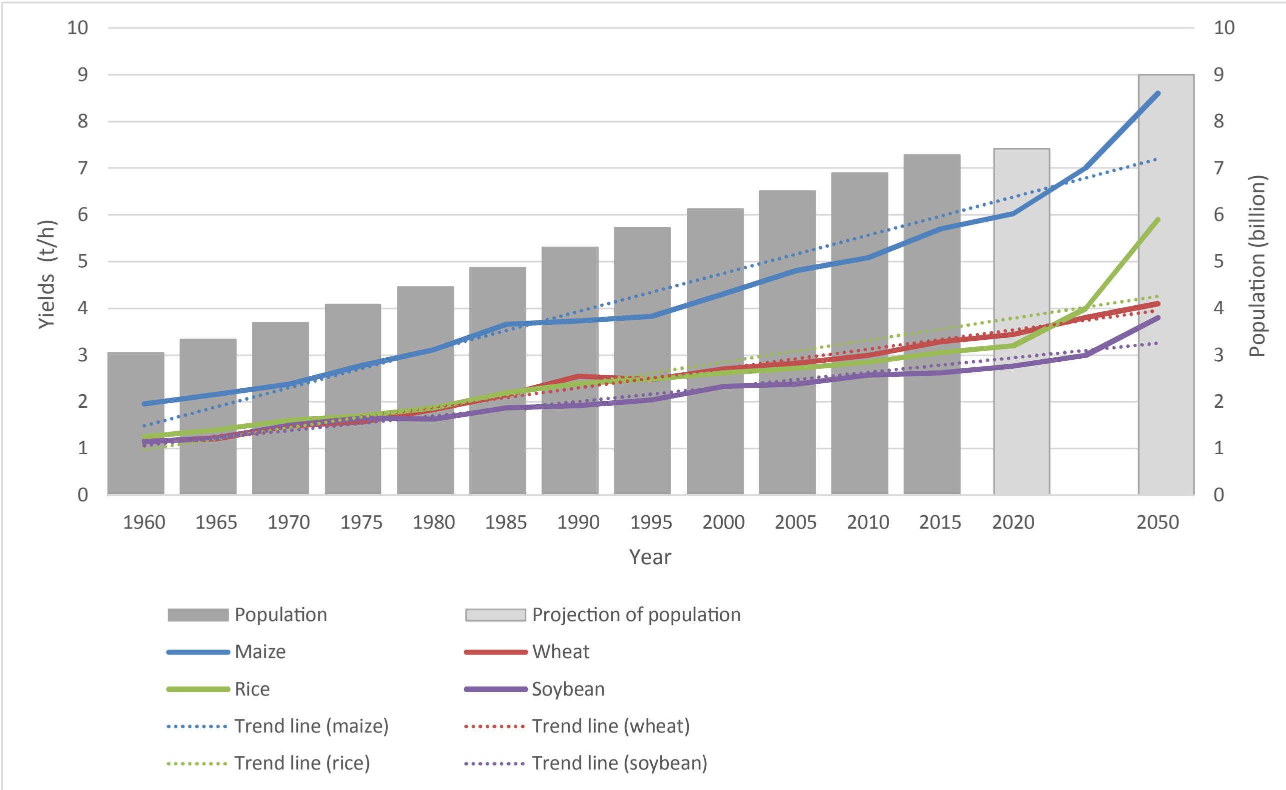

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Figure 1. Yields of Selected Crops from 1960s to 2050 Against Population Growth: Past, Present, and Future. The global increase in maize, wheat, rice, and soybean yields against population growth between the 1960s and 2016. The required and predicted (based on current increase levels) production of the four main crops in the 2050 perspective are indicated. As seen, population growth determines the increase in the yield of crop species and constitutes a significant challenge for ensuring food safety in the next decades. The highest growth has been observed in maize yields, from 1.95 t/ha in 1960 to 5.7 t/ha in 2015 (192% growth compared with the 1960s). Adapted from[vi,xx].

Similar to GM wheat, there are eight registered modification events in rice[ix], but none of them are cultivated on a large scale. Among other modifications, rice plants have been modified to tolerate herbicides, resist pests, accelerate photosynthesis, and increase grain size. The best-known example of biofortification is ‘golden rice’, a variety with added β-carotene (a precursor of the vitamin A synthesis pathway) [32].

Interestingly, new directions in the creation of GM plants are being tested, like the introduction of basic C4 photosynthesis into a rice cultivar (a C3P plant) [33]. It is estimated that the introduction of the C4 photosynthesis pathway has the potential to increase crop yield by an additional 50% and can be beneficial to other C3P crops like soybean, wheat, or potatoes [33]. Engineering nitrogen-fixing cereals is yet another important direction in the creation of GMOs essential for sustainable food production [34]. Introducing the ability to perform symbiosis with nitrogen-fixing bacteria would also lead to a significant decrease in N fertilizer use.

The third generation of GM crops aims to ‘biomanufacture’ pharmaceuticals, vaccines, and industrial compounds in traditional crops engineered into plant-made pharmaceuticals (PMPs) or plant-made industrial products (PMIPs). At the beginning, this was considered a promising approach, in which more plentiful pharmaceutical drugs and industrial products, such as

Table 1. Comparison of Production Rates and Production Growth Increase of the Most Important Crops in 1961 and 2016

Crop	Production (million tons)[a]		Production growth increase (%)[b]
	1961	2016	
Maize	205	1.060	417
Rice	215.6	740.9	244
Wheat	222.3	749.4	237
Soybean	26.8	334.8	1146
Rapeseed	3.5	68.8	1815

[a]Adapted from[vi,xx].
[b]Calculation based on formula (2016–1961)/1961.

Table 2. Utilization of Crops in EU Countries and in the World in 2017

Utilization of crops in 2017 (%)[a]					
	Maize	Rice	Wheat	Soybean	Other oilseeds (rapeseed, sunflower, groundnuts)
In EU countries					
Feed	79	0	43	–	–
Food	7	100	42	0	2
Crush[b]	–	–	–	91	93
Biofuel use	10	0	4	–	–
Other use	4	0	11	9	5
In the world					
Feed	60	4	20	–	–
Food	14	81	67	5	13
Crush[b]	–	–	–	90	85
Biofuel use	18	0	2	–	–
Other use	8	15	11	5	2

–, lack of use or data.
[a]Adapted from[vi].
[b]Refers only to oilseeds. Soybeans are processed into soybean meal (using in feed industry) and soybean oil (using in food industry) through a process known as crushing.

plastics, cosmetics, enzymes, and epoxies, could be manufactured [35,36]. However, due to past events associated with contamination in the field and, therefore, societal mistrust, such GM crops necessitate advanced legal regulations to prevent them from being introduced into the food chain [37].

In 2017, over 50% of GM crop areas planted were used for GM soybeans (91.4 million ha), mostly the herbicide-tolerant varieties and the Intacta™ soybean, which tolerates the herbicide glyphosate and resists caterpillars[viii]. Maize planted on 59.7 million ha worldwide, which constitutes a 1% decrease relative to 2016, was the second-most widely grown GM crop. Transgenic canola with low erucic acid content was the fourth-most popular GM crop planted, with a global area of 8.6 million ha. These crops are not planted uniformly across the world; in 2017, the acreage of GM plants in developing countries surpassed that in industrial countries

Box 1. Milestones in Agriculture

Over the past century, humanity has witnessed several milestones that have significantly increased agricultural productivity. Initially, the improvement of arable crops was based on the assessment and judgment of farmers who, for cultivation and breeding purposes, chose good-quality plants with high yields. The introduction of chemical fertilizers (as early as the 19th century) and pesticides and herbicides (after World War II) boosted the crops' yields [59]. The 'Green Revolution', started in the 1940s in Mexico by Dr Borlaug, led to another substantial increase in crop yields. The new varieties obtained via traditional breeding were not only disease resistant but also better at adapting to various growth conditions, possessing an increased yield potential[xviii,xix]. In India, for example, between 1948 and 1997 grain food production quadrupled (from 50 to 198 million tons) [60]. Similar trends have been observed in other parts of the world. In the USA from the 1930s to the early 2000s, corn yields increased nearly sixfold (from 1.6 t/ha to 9.5 t/ha). Such a dramatic improvement in yield has been attributed to the use of synthetic fertilizers, plant protection via pesticides and herbicides, and the development and widespread use of improved crop varieties and farm machinery [61]. Another milestone of agricultural production was made possible by the use of a wide range of biotechnology tools. The manipulation of genetic information and the creation of GM plant varieties became a reality at the end of the 20th century, when the first GMOs were introduced into the market [62].

by 11.4 million ha. Table 3 shows the top ten countries leading the production of GM crops. The biggest EU producer of GM crops, Spain, ranks 16th in the world [38].

Are GM Plants a Solution for Ensuring Food Security?

Agricultural production is the most important element of agrobiotechnology, representing a significant sector of the world's economy and stretching far beyond food production. Traditional gene engineering methods and recently developed genome editing-based **new breeding techniques (NBTs)** are promising tools that provide hope for the future of agriculture, as GM crops can help address some of the challenges lying ahead. The priority should be the safety of the food that is produced, not the methods by which new traits and properties are incorporated. Analyses of the safety of GM crops among 1783 research studies [39] revealed that no significant hazards can be directly connected to GM foods. Similarly, amid 128 000 cases of food-borne illnesses leading to hospitalizations and 3000 deaths, none was linked to transgenic foods, concluding that the risk to human health from foods contaminated with pathogens is far greater than that from GMOs [40]. These observations may be connected to lower contents of mycotoxins (29%), fumonisin (31%), and thricotecens (37%), as reported for GM maize grains compared with its non-GM counterparts [18]. Fungal contaminations are facilitated and promoted by insect attacks (via physical injuries to plant tissues); hence, an observed 59.6% decrease in damage in GM maize lines [18] resulted in lower contamination by fungi [41].

Table 3. Comparison of Acreage of GM Crops (in Millions of Hectares) Planted in 2016 and 2017

	Country	2016[a]	2017[a]	Increase/decrease from 2015 to 2016
1	USA	72.9	75	2.1
2	Brazil	49.150.2	1.1	4.9
3	Argentina	23.8	23.6	−0.74.−0.2
4	Canada	11.6	13.1	1.5
5	India	10.8	11.4	0.6
6	Paraguay	3.6	3.0	−0.6
7	Pakistan	2.9	3.0	0.1
8	China	2.8	2.8	0
9	South Africa	2.7	2.7	0
10	Uruguay	1.3	1.1	−0.2

[a]Adapted from [38].

The introduction of herbicide-resistant crops has resulted in a switch to glyphosate-based herbicides [42]. Since glyphosate targets EPSPS, an enzyme involved in the shikimate pathway present in plants, microorganisms, and some animals [43], it is of lesser overall toxicity to most animals and humans. The infamous studies of Serralini and colleagues showing an increased risk of mice developing cancer when fed glyphosate-resistant maize that were initially published in 2012 have been directly refuted with statements that GM maize varieties did not trigger any negative effects in the trial animals[x] [44].

Importantly, with the introduction of GM crops, the total amount of herbicides and pesticides used in agriculture decreased significantly [45,46]. However, there are further benefits from GM crops, including increases in crop yield without expanding the cultivation area, reductions in fertilizer use, and reductions in greenhouse gas emissions via enabling of sustainable practices. Approximately an additional 13 million ha of cultivation area would have been necessary by 2010 if farmers had not been using GMOs [47]. The elimination of GM crops from cultivation would demand an increase in the global cropping area at the expense of rainforests [48], which would intensify carbon dioxide emission and, therefore, significantly contribute to climate change [49]. Moreover, greenhouse gas emissions can be further diminished by applying no-tillage agricultural practices on GM crop fields [50,51].

Last but not least, the increase in yield, production gains, and cost savings of GM crop cultivation by 18 million farmers worldwide resulted in economic benefits of US$15.4 billion in 2015 and a total of US$167.8 billion between 1996 and 2015 [52]. Additionally, the introduction of GM crops allows effective shortening of the production cycle for soybean, which enabled many farmers to plant it as a secondary crop after wheat in the same season [52].

Social Acceptance and Legislation on GM Crops

To prevent further restrictions on the production of GM crops, public acceptance of new biotechnologies in agriculture is urgently needed. First, to increase the societal acceptance of genetic modification in agriculture, we must ensure that research in biotechnology and bioscience is presented in an understandable and clear manner [53]. With the advent of NBTs, it is extremely important to engage the scientific community in the discourse on biotechnologies and to prevent discussions based on inaccurate or false information. Importantly, modified plants created using NBTs might be more acceptable to society as these tools allow more precise genetic changes. Additionally, from the perspective of increasing the competitiveness of European agriculture and implementing the Common Agricultural Policy, the use of NBTs in practical breeding becomes a necessity. The EU has incurred large investment costs in research as well as in NBTs. However, the use and dissemination of innovations in the **bioeconomy** sectors is not possible without clear legal regulations and the involvement of policy measures in promoting technologies that serve intelligent and sustainable development [54,55].

Notably, outside the EU, new GM varieties are constantly being approved for consumption and production. In June 2017, GM sugarcane resisting attack by the cane borer was approved for cultivation in Brazil[xi]. Since November 2017, GM non-browning apples [56] have been sold in US supermarkets. The commercial sale of food derived from the GM rice line known as golden rice was approved in Australia and New Zealand[xii] in December 2017 and in Canada in March 2018[xii]. In the EU, however, fears and mistrust of transgenic technology have led the governments of many countries to implement restrictions on the growing of GM crops. Nineteen of 27 EU countries declared 'GMO-free zones', taking advantage of the 'opt-out' strategy[xiv]. Although, at the level of the European Parliament, ten GM varieties have been fully approved

Box 2. EASAC Recommendations on New Plant Breeding Techniques (Adapted from[xv])

(i) The EU policy development for agricultural innovation should be transparent, proportionate, and fully informed by advancing scientific evidence and experience worldwide.
(ii) It is time to resolve current legislative uncertainties. We ask that EU regulators confirm that the products of NBTs, when they do not contain foreign DNA, do not fall within the scope of GMO legislation.
(iii) The aim in the EU should be to regulate a specific agricultural trait and/or product, not the technology used.
(iv) The European Commission and Member States should do more to support fundamental research in plant sciences and protect field trials of novel crop variants.
(v) Modernizing EU regulatory frameworks would help to address the implications of current policy disconnects in support of science and innovation at regional and global levels. At the same time, there is a continuing need for wide-ranging engagement on critical issues, which should include re-examining the appropriate use of the precautionary principle.

for planting (seven carnation, one potato, and two maize varieties), only maize MON810 is being grown, on 136 363 ha in four EU countries: Spain (129 081 ha), Portugal (7069 ha), Slovakia (138 ha), and the Czech Republic (75 ha) [39]. In opposition to the opt-out strategy, European scientists recently proposed an 'opt-in' strategy, suggesting that legislation that will allow EU countries to individually authorize the cultivation of GM crops should be developed [57].

In the EU, a total of 95 traits incorporated into crop plants via genetic modification have been approved for food, feed, and processing, but the products derived from or containing GMOs are strictly controlled, with zero tolerance for unauthorized GMO use[xv].

With respect to NBTs, according to current legislation the European Academies Science Advisory Council (EASAC) has claimed that the products of NBTs, when they do not contain foreign DNA, do not fall within the scope of GMO legislation (Box 2). In the USA, CRISPR–edited *Camelina sativa* (false flax) containing an increased content of omega-3 fatty acids in oil can be cultivated and sold free from regulation, as the USDA has given it a free pass [56].

Concluding Remarks and Future Perspectives

Despite the great achievements of past centuries, the need to improve existing varieties and increase agricultural production remains a pressing issue, as it is associated with the continuous growth of the human population and with global climate change, which is accompanied by the exposure of organisms to greater biotic and abiotic stresses. Intensive agriculture practiced over the past decades with only one aim – to increase yield, without adherence to ecological or scientific principles – has led to loss of soil health, soil erosion, pollution, salinization, desertification, and depletion of freshwater resources and agrobiodiversity [4]. If we are to resume progress towards eliminating hunger, a sustainable model for intensive agriculture combining the lessons from history with the benefits of modern biotechnology should be elaborated and practiced (see Outstanding Questions).

Sustainable intensification of agricultural production can be defined as a process or a system in which the yield is increased without exerting a negative impact on the environment and without increasing the crop area. This concept focuses on specific goals rather than on methods. It does not determine the technology, species, or single range of measures that should be used. Sustainable intensification emphasizes and seeks to achieve broad goals, not simply an increase of agricultural productivity, and therefore should involve several rules[xvi,xvii] [1] (Box 3).

Challenges in the development of the economy and, among other factors, ensuring food security have been highlighted in *Bioeconomy for Europe* issued by the EU [58]. According to this document, people must radically change their approach to the production and consumption as well as the processing, recycling, and disposal of biological resources. It is necessary to

Outstanding Questions

Achieving food security by 2050 for a forecasted 9 billion people is challenging. Considering the noticeable downturn in soil condition, climate change, and increased biotic and abiotic stresses that diminish yields of conventional crops, will the further necessary increase in crop production be possible?

While facing discouraging trends in food production, are plants genetically engineered to survive in unfavorable climatic conditions, possessing resistance to pests or herbicides, and with better nutritional values a solution to food security dilemma? The need to expand agricultural land areas to achieve an increase in conventional crop yields often comes at the cost of rainforests, which leads to further escalation of greenhouse gas emissions. The use of GM/NBT plants provides an opportunity to reduce the yield loss (due to stresses) or increase crop production without the need to expand the arable area, thus preventing further destruction of the land.

Sustainable intensification of agricultural production, a system in which the yield is increased without exerting a negative impact on the environment and without altering the crop area, relies on the optimization of resource utilization and management. Such transition is necessary, but can we implement the sustainable intensification of agricultural production?

Without broad acceptance of new biotechnologies in agriculture, we will not be able to achieve progress in agrobiotechnology, nor ensure food security. Therefore, the most pressing question is how can we present the benefits of GMOs in a transparent and comprehensible way, especially in the EU, while clearly describing the risks associated with the use of GM crops?

Box 3. Guidelines for Sustainable Intensification of Agricultural Production (Adapted from[xvi,xvii] and [3,4])

- Use plant varieties that ensure the highest productivity in a given geographic location and under certain environmental conditions.
- Avoid unnecessary supply of energy and other external resources, such as fertilizers, chemical plant protection products, or additional water resources. Rotating annual and cover crops and practicing direct manure application and no-till agriculture should be encouraged. 'Conservation agriculture' helps to restore soil organic matter, nutrients, structure, and water-holding capacity and averts soil loss while benefiting crops.
- Use natural phenomena, such as the circulation of nutrients, biological binding of N, allelopathy, predation, or parasitism. Biotechnology should be used to dishabituate crops from the artificial world that humanity has created for them.
- Recycle nutrients from sewage to diminish the demand for chemical fertilization. Inorganic fertilizers could be manufactured from human sewage in biorefineries.
- Bring existing agronomic technology and know-how to farmers as well as food producers and consumers, to change their approach to the production, consumption, processing, recycling, and disposal of biological resources.
- Build educational, technical, research, and storage capacity, food processing capability, and other aspects of agribusiness, rural transportation, and water and communications infrastructure.
- Use human capital efficiently based on knowledge and the ability to adapt innovative solutions both on a local scale and in the systemic approach to the sustainable management of water resources and land and pest management.
- Minimize the share of technologies that have a negative impact on greenhouse gas emissions, drinking water resources, carbon sequestration, biodiversity, and the environment or human health.
- Mind sociological factors, such as social acceptance of transgenic plants, and other solutions offered by biotechnology.
- Create legal and political frameworks that will enable the commercialization of research results and provide impetus to their further implementation.

maximize the use of current food and feed resources and increase and change agricultural production. The concept of a bioeconomy provides an opportunity to create global food security, improve nutrition, manufacture products based on natural materials (bioproducts), and provide support for agriculture, forestry, and other ecosystems [58].

Society wrongfully perceives that most of the benefits of GM crops are received by farmers and multinational corporations (developers of the technology/new varieties), discarding scientific proof of the safety of GM foods, increased crop yields (without the expansion in cultivation area), reduced herbicide, pesticide, and fertilizer use, reduced greenhouse gas emissions, and the enabling of sustainable agricultural practices. To a large degree, this happens due to a lack of honest and reliable information on GM crops diffused by the opponents of GMOs and lack of interest from the scientific community in sharing the results of thousands of studies showing no GMO harm to humans or the environment. Therefore, to be able to use GM varieties in the future, we must change the minds of the people of the world. With the rise in minimum risks or ethical doubts in society, the newest biotechnology achievements must be thoughtfully and sustainably incorporated into agricultural practice. Only then will we be able to face the challenges of modern and sustainable food production systems.

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Resources

[i] www.data.worldbank.org

[ii]www.fao.org

[iii]www.fao.org/docrep/005/y4252e/y4252e06.htm

[iv]www.fao.org/news/story/en/item/1126971/icode/

[v]http://ec.europa.eu/environment/integration/research/newsalert/pdf/IR5_en.pdf

[vi]www.agri-outlook.org/

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[viii]www.isaaa.org/gmapprovaldatabase/event/default.asp?EventID=159

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